Critical Components for Direct Fuel Cell/Turbine Ultra-Efficiency System

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FuelCell Energy Inc. (FCE) is developing ultra high efficiency fuel cell/Turbine (DFC/T®) hybrid power plants. The DFC/T power system is based on an innovative power cycle utilizing an indirectly heated gas turbine to supplement fuel cell generated power. Features of the DFC/T system include: electrical efficiencies of up to 75% on natural gas, minimal emissions, simplicity in design, direct reforming internal to the fuel cell, reduced carbon dioxide release to environment, and potential cost competitiveness with existing combined cycle power plants. The combined fuel cell and turbine system does not require any combustion in the turbine. Emissions from DFC/T systems are expected to be less than 0.001 lb/million BTU for sulfur and nitrogen oxides, a significant improvement over existing power plants.

The DFC/T system development is being conducted under the Department of Energy's Vision 21 Program through the Office of Fossil Energy and managed by the National Energy Technology Laboratory (NETL). The project objectives are the design of a 40 MW system utilizing the internally reformed Direct FuelCell®(DFC) technology being commercialized by FCE. The development, design and testing of the key components for the DFC/T are the focus of the Vision 21 project.

An important aspect of the hybrid fuel cell/turbine system design is the synergistic operation of the fuel cell stack, which is an electrochemical device, and the gas turbine, which is a mechanical power generator. In order to address this issue, the DFC/T development project includes construction and testing of a subMW DFC/T power plant prototype at FCE headquarters. To date, significant progress have been achieved in proof-of-concept tests of the sub-scale power plant built around a state-of-the-art DFC stack integrated with a modified Capstone Model 330 Microturbine. The objectives of this effort are to investigate the integration aspects of the fuel cell and turbine and to obtain design information and operational data that will be utilized in the design of a 40-MW high efficiency Vision 21 power plant. Additionally, these tests are providing the valuable insight for DFC/T power plant potential for load following, increased reliability, and enhanced operability. The results from the sub-scale hybrid tests along with any experience gained in operating the fuel cell and microturbine will be utilized in the development of larger (MW scale) Vision 21 power plants.

Acknowledgements

The development of Direct Fuel Cell®/Turbine hybrid power system is being performed as a cost-shared Vision 21 project supported by the US Department of Energy through the National Energy Technology Laboratory (NETL). The technical guidance of Mr. Richard Dennis, the DOE Contracting Officer's Representative (COR) is acknowledged. This project has also substantially benefited from the guidance and directions of Mr. Tom J. George and Ms. Abbie Layne of NETL.

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INTRODUCTION

Direct FuelCell® / Turbine

- FUELCELL ENERGY, INC (FCE) IS CURRENTLY INVOLVED IN THE DEVELOPMENT OF FUEL CELL/TURBINE HYBRID POWER PLANTS UNDER A VISION 21 PROJECT SUPPORTED BY THE US DEPARTMENT OF ENERGY (DE-FC26-00NT40798)

  - Technology development is focused on the integration of FCE's Direct FuelCell® (DFC®) with Gas Turbines in an ultra high efficiency power plant configuration.

VISION 21 PROJECT

OBJECTIVES

- DESIGN OF 40 MW HYBRID POWER PLANT
- SYSTEM EFFICIENCY > 75%
- COST COMPETITIVE WITH OTHER ENERGY SYSTEMS
- ULTRA LOW EMISSIONS: <.01 lbs/MMBTU of SO_x and NO_x

VISION 21 PROJECT

PROJECT PLAN

- DESIGN OF 40-MW DFC®/TURBINE POWER PLANT
- SUB-SCALE FUEL CELL/TURBINE INTEGRATION TESTS
- HIGH EFFICIENCY FUEL CELL DESIGN
- BOP COMPONENTS FOR 40 MW POWER PLANT:
    - HIGH TEMPERATURE ANODE EXHAUST OXIDIZER
    - RECUPERATORS
    - GAS TURBINE

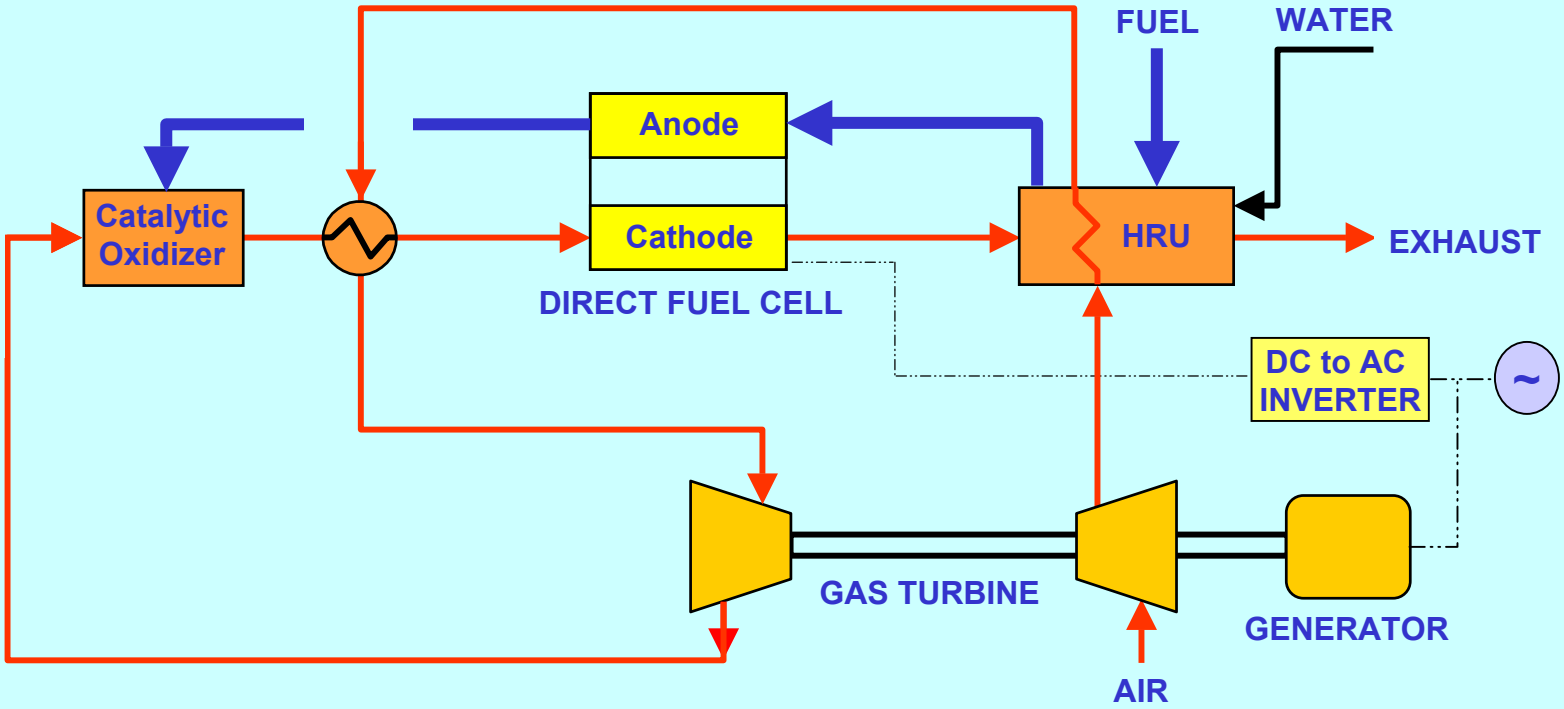
OVERVIEW

OF

ULTRA HIGH EFFICIENCY

DFC/T® TECHNOLOGY

HIGH EFFICIENCY HYBRID DFC® / TURBINE POWER PLANT

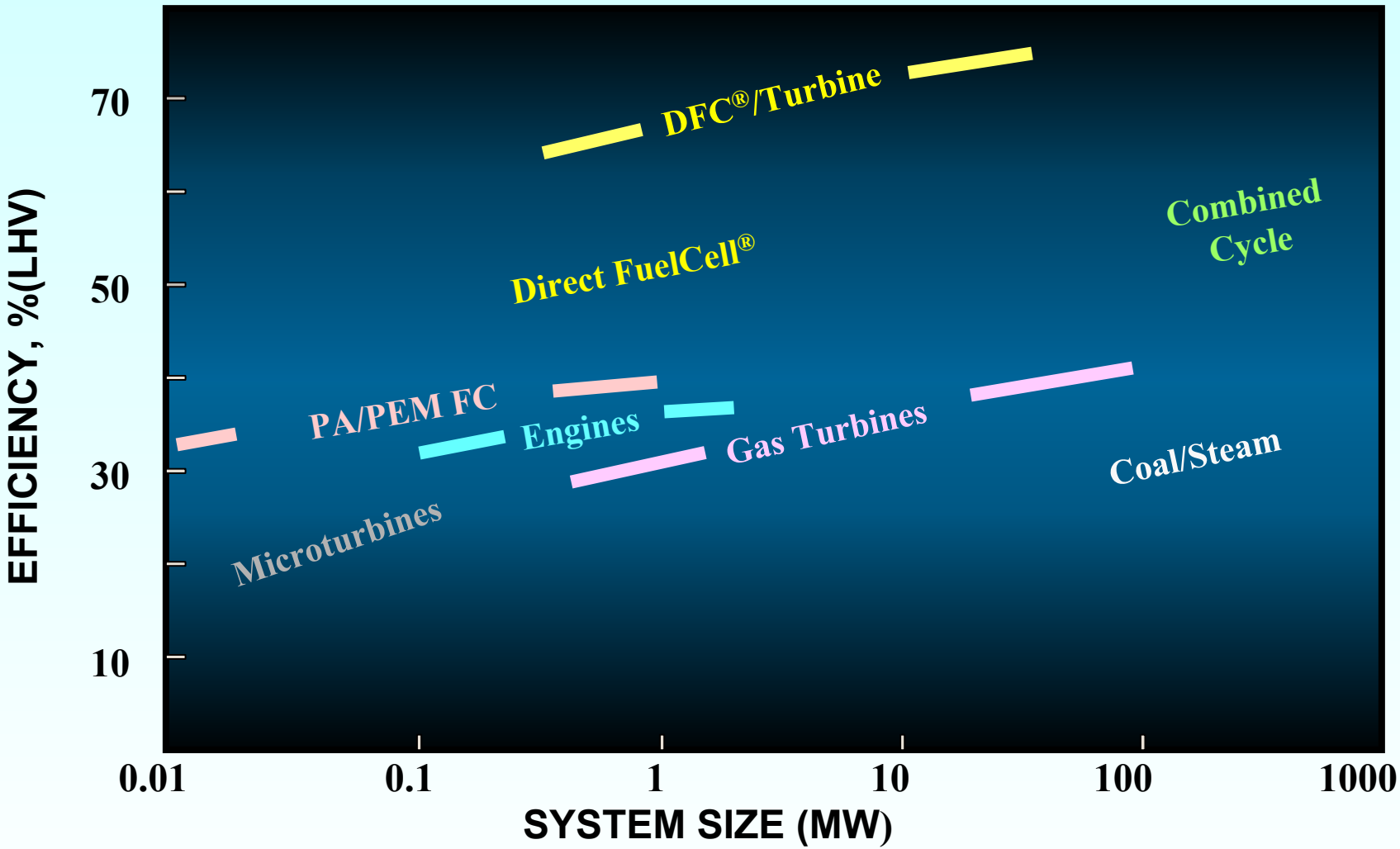


- *Low Cost of Electricity Compared to Combined Cycles*
- *Efficiencies of ~ 75% are possible*

ADVANTAGES OF DFC/T® SYSTEM

- **FUEL CELL IS PRIMARY SOURCE OF POWER GENERATION**
- **TURBINE PRESSURE RATIO INDEPENDENT OF AMBIENT PRESSURE FUEL CELL**
- **FLEXIBILITY IN OPERATION OF FUEL CELL AND TURBINE**
- **SIMPLICITY OF DFC® DESIGN AND INTERNAL REFORMING FEATURE RETAINED**
- **NO NATURAL GAS COMPRESSION REQUIRED (UNLESS A SUPPLEMENTAL DIRECT FIRING OF TURBINE IS DESIRED)**
- **PROJECTED LOW COST AND HIGH EFFICIENCY**

Comparative Efficiencies of Electric Power Plants



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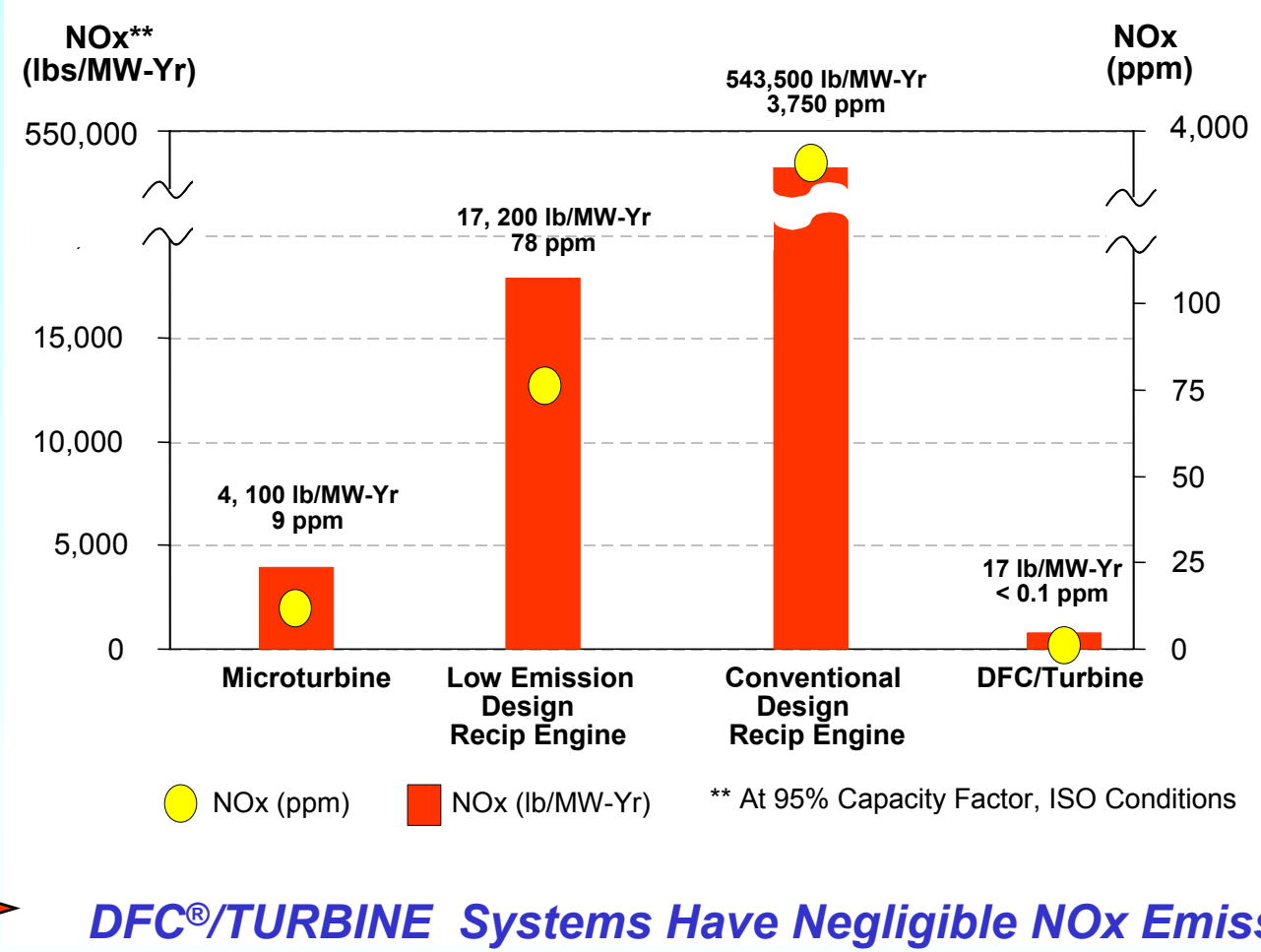
NO_x EMISSIONS PRODUCED BY VARIOUS TECHNOLOGIES



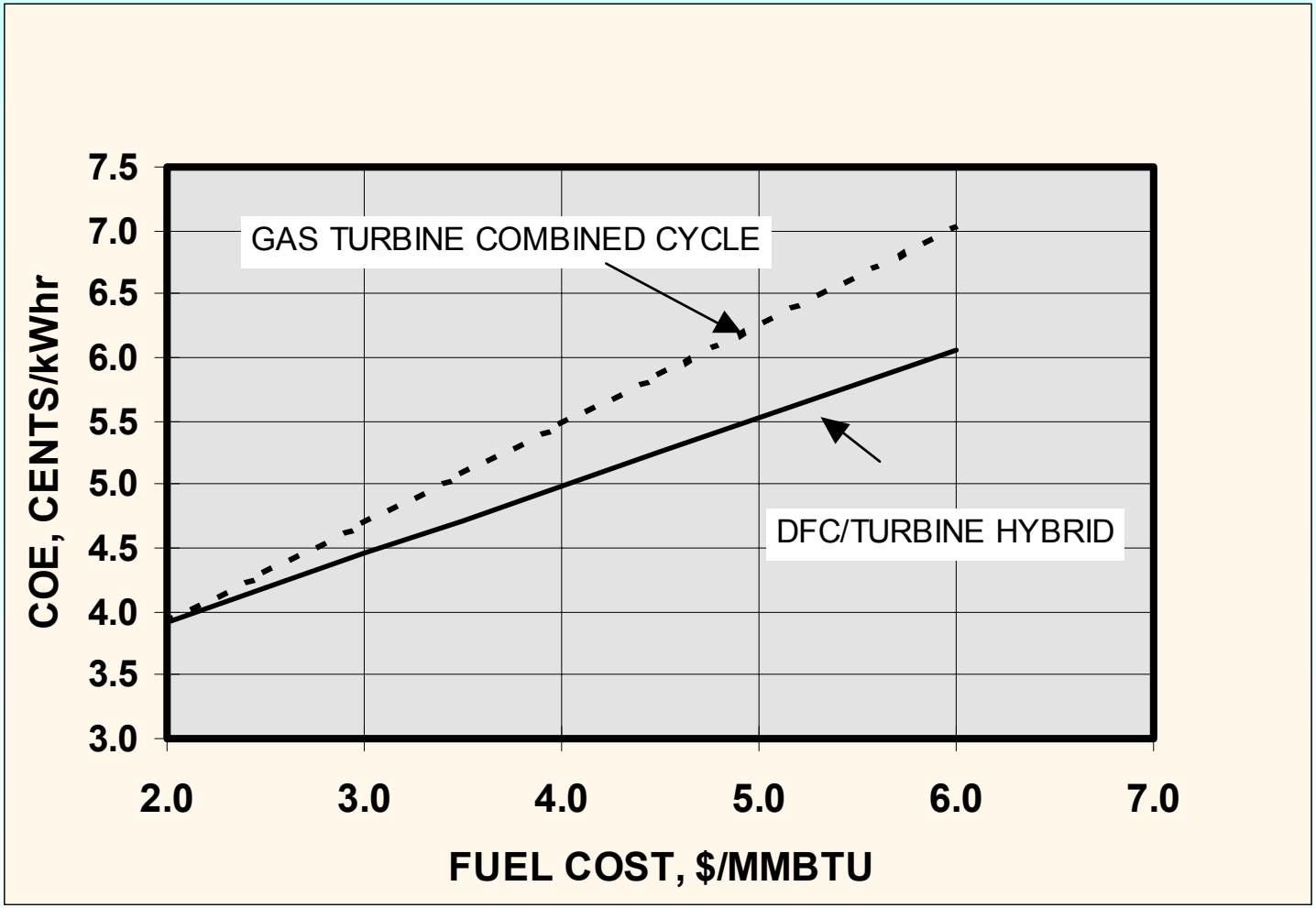
DFC®/TURBINE Systems Have Negligible NOx Emissions

Product Development for 10-50 MW Applications

20 MW Ultra–High Efficiency DFC® /Turbine Power Plant

FuelCell Energy, Inc.

COST OF ENERGY: Comparison of GT Combined Cycle with DFC/Turbine Hybrid



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VISION 21

SUBSCALE DFC®/TURBINE

INTEGRATION TEST

SUBSCALE DFC®/MICROTURBINE INTEGRATION TESTS

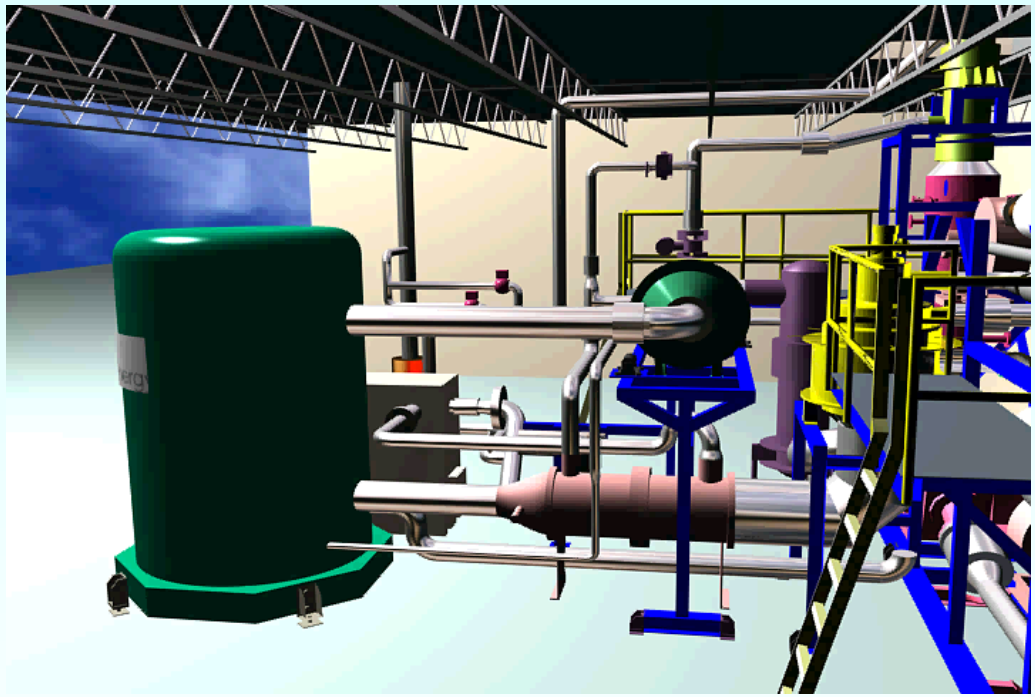
OBJECTIVES

- Proof-of-concept of DFC/T® system by integrating a 250kW DFC® stack with a microturbine in a sub-MW power plant
- Gain operational and design experience
- Develop and identify the design of critical components for 40 MW DFC/T® system

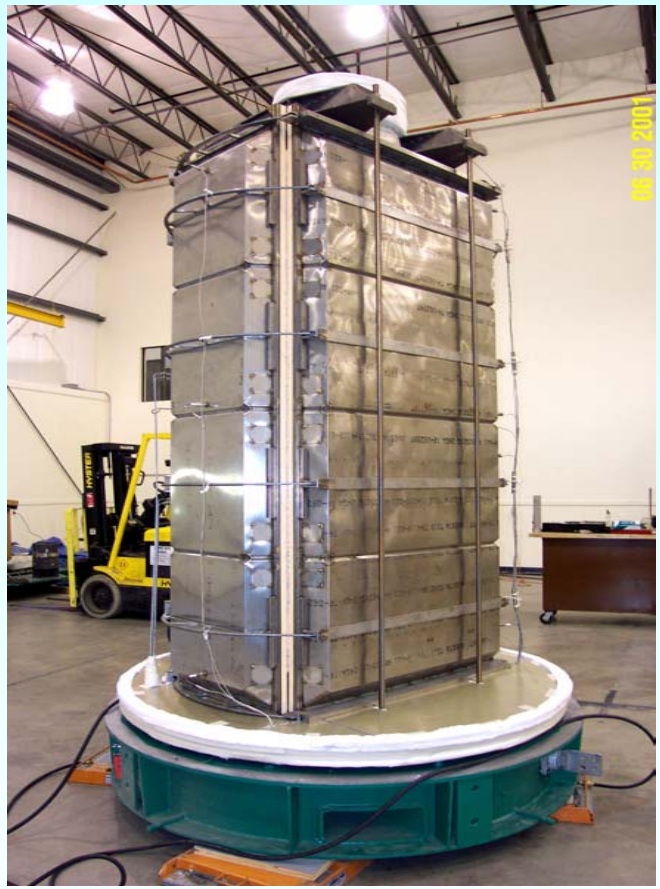
SUB-MW CLASS DFC/T POWER PLANT OPERATING MODES

The power plant is designed to operate in dual mode

- FUEL CELL CONDITIONING
- DUAL MODE OF OPERATION
  - FUEL CELL ONLY
  - INTEGRATED FUEL CELL/TURBINE
- RESTART / SHUTDOWN



FULL-SIZE STACK ACCOMPLISHMENT



FA-100-2 BUILT WITH LOW COST NON-REPEAT COMPONENTS

MODIFICATIONS OF MICROTURBINE FOR DFC/T TESTS

- MECHANICAL / DESIGN MODIFICATIONS
- MATERIALS
- CONTROL / DATA COMMUNICATION

CAPSTONE MODEL 330
(Simple Cycle)

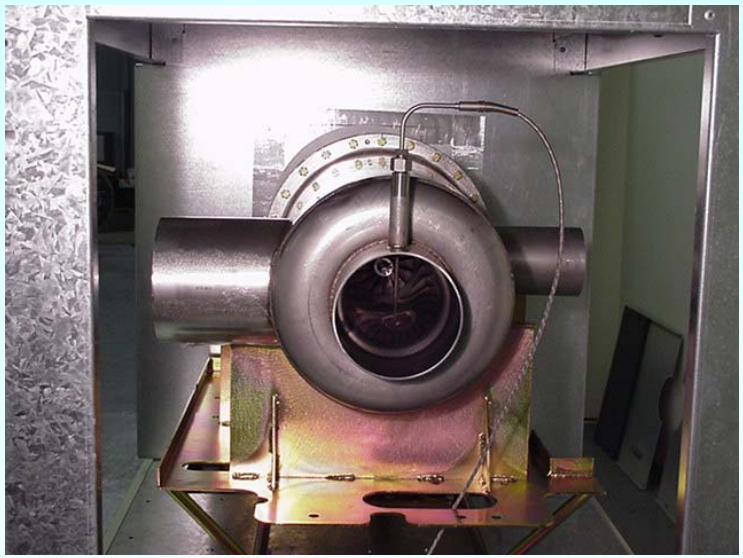
MECHANICAL / DESIGN MODIFICATIONS OF MICROTURBINE

- **IMPROVED THRUST BEARING CAPABLE OF >20 IWG**
- **INLET/OUTLET PORT CONNECTIONS TO THE BALANCE-OF-PLANT**
- **MODIFIED CASING**

CONTROL/ SOFTWARE MODIFICATIONS OF MICROTURBINE

- COMMUNICATION OF MICROTURBINE'S CONTROLLER / DATA ACQUISITION HARDWARE TO FCE'S CONTROL SYSTEM
- MICROTURBINE CONTROL SOFTWARE MODIFICATIONS
  - Speed Control
  - Expander Inlet Temperature Control
- SURGE AND TRIP CONTROL

MODIFIED CAPSTONE SIMPLE CYCLE MicroTurbine™

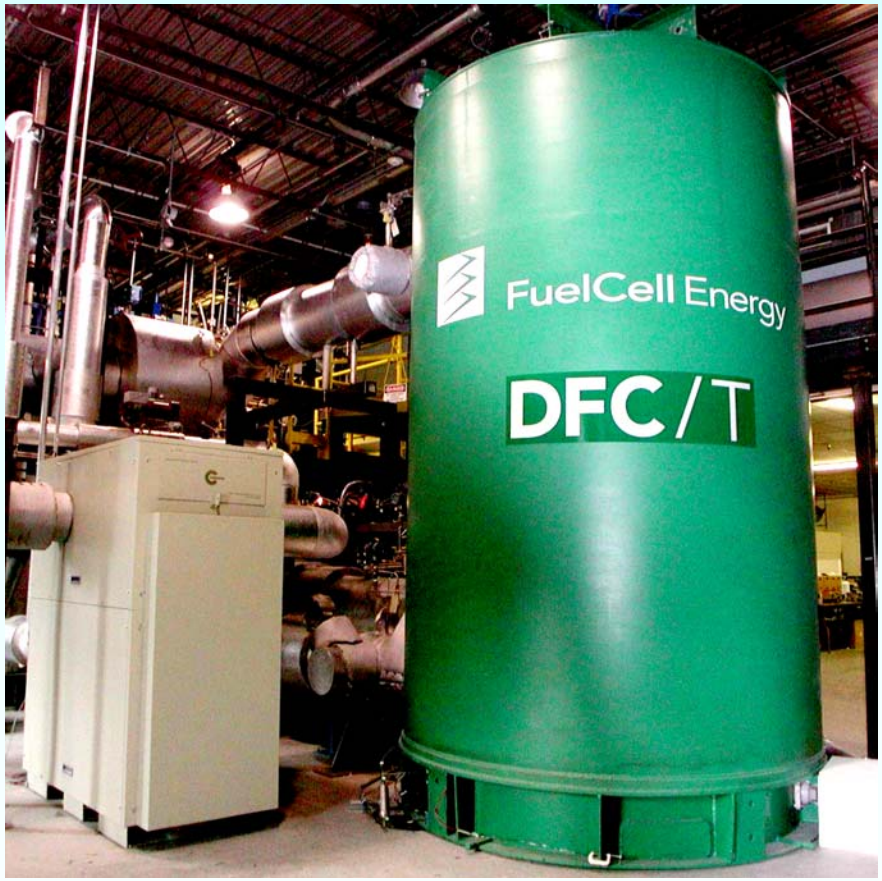


Capstone Simple Cycle Model 330 MicroTurbine™ at FCE Test Area

POWER PLANT CONSTRUCTION AND TESTING

Vision 21 Project Milestone

250kW DFC® stack integrated with a Capstone 330 Microturbine



Objectives Met

- Verified DFC/T® Concept
- Modes of Operation Tested:
  - Fuel Cell Only
  - Fuel Cell with Turbine Integrated and Operated at Various Operating Conditions
- Thermal Management Confirmed
  - Fuel Cell Operating Temperature
  - MT Expander Inlet Temperature
- Trip/Emergency Scenarios Tested and Successful
- Refinement of Control Strategies thru Operational Experience
  - Validation of Control Philosophy for Commercial Production

FUTURE WORK PLANS

- **Continue sub-scale DFC/T power plant tests and implement refinements for optimal power and efficiency**
- **Complete design of the 40 MW DFC/T power plant**
- **Investigate suitable gas turbine and recuperator technologies for the 40MW plant**
- **Develop design of fuel cells for operation at high fuel utilization**